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(54) **DYNAMIC BLEEDER CURRENT CONTROL FOR LED DIMMERS**

(71) Applicant: **Dialog Semiconductor Inc.**, Campbell, CA (US)

(72) Inventors: **Xiaoyan Wang**, Milpitas, CA (US); **Nan Shi**, Newark, CA (US); **Clarita Chiting Knoll**, San Leandro, CA (US); **Guang Feng**, Cupertino, CA (US)

(73) Assignee: **Dialog Semiconductor Inc.**, Campbell, CA (US)

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H05B 37/02 (2006.01)
H05B 33/08 (2006.01)

(52) **U.S. Cl.**
CPC ***H05B 33/0818*** (2013.01); ***H05B 33/0845*** (2013.01); ***H05B 33/0887*** (2013.01)

(58) **Field of Classification Search**
CPC H05B 33/0815; H05B 33/0803; H05B 33/0827; H05B 33/0809; H05B 33/0845; H05B 33/0824; H05B 37/02; H05B 37/029; Y02B 20/347; Y02B 20/42
USPC ...... 315/291, 294, 297, 307, 312, 360, 185 R
See application file for complete search history.

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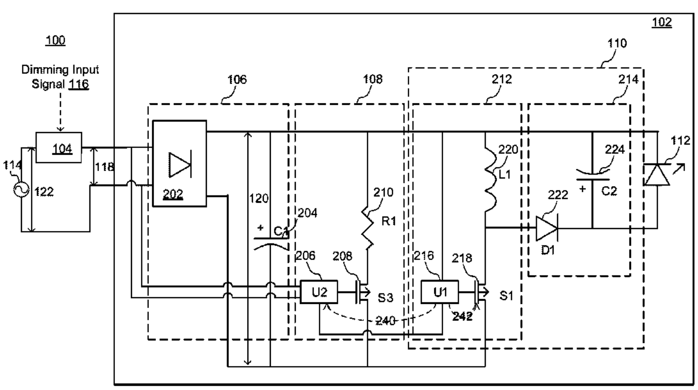
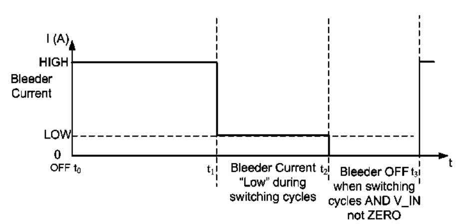
Primary Examiner — Haissa Philogene
(74) *Attorney, Agent, or Firm* — Fenwick & West LLP

(57) **ABSTRACT**

LED lamp systems as described herein include a dimmer switch and a bleeder circuit. The bleeder circuit provides a bleeder current to management voltage and to prevent the dimmer switch from turning off prematurely. The bleeder circuit may monitor the AC input voltage outputted by the dimmer switch. When the AC input voltage is less than a first threshold, the bleeder circuit provides a bleeder current. When the AC input voltage is greater than a second threshold, the bleeder circuit adjusts the bleeder current to less than a predetermined level.

18 Claims, 4 Drawing Sheets





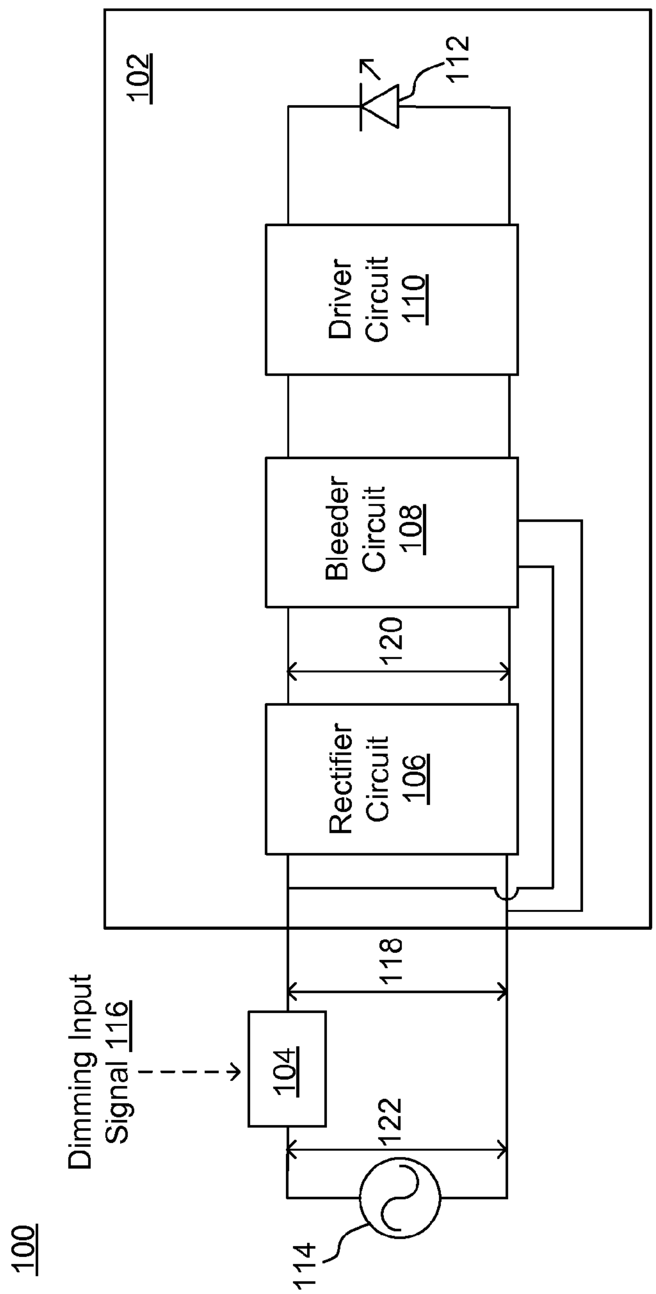

100
102
104
Dimming Input Signal 116
Rectifier Circuit 106
Bleeder Circuit 108
Driver Circuit 110
112
114
118
120
122

FIG. 1

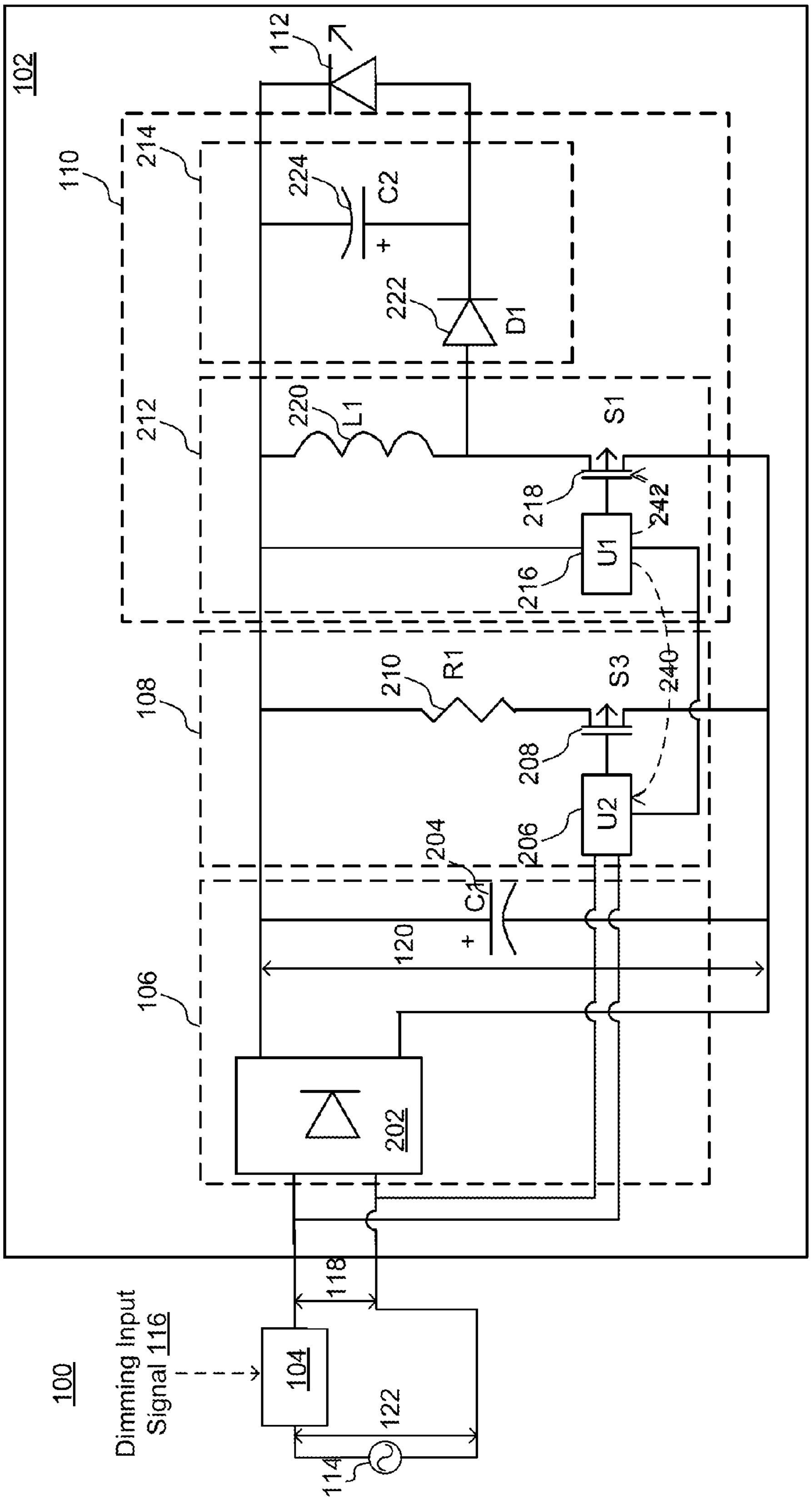

102
110
214
224
C2
+
112
222
D1
212
220
L1
S1
218
242
U1
216
108
210
R1
S3
240
208
U2
206
204
C1
+
120
106
202
118
100
Dimming Input Signal 116
104
122
114

FIG. 2

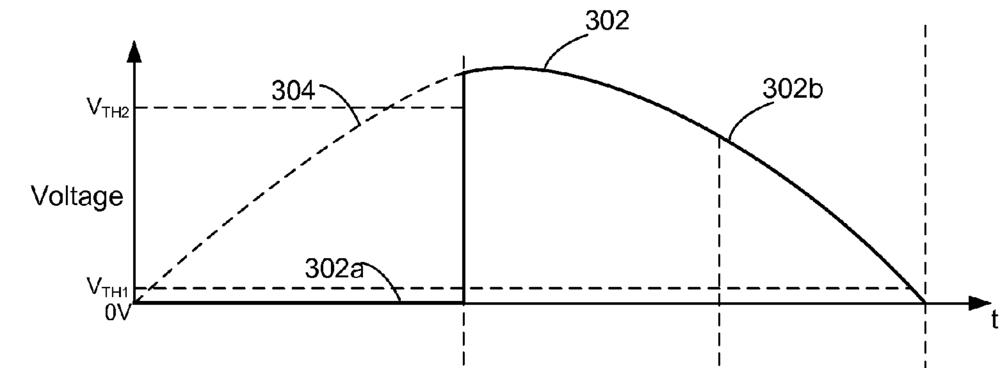


FIG. 3A

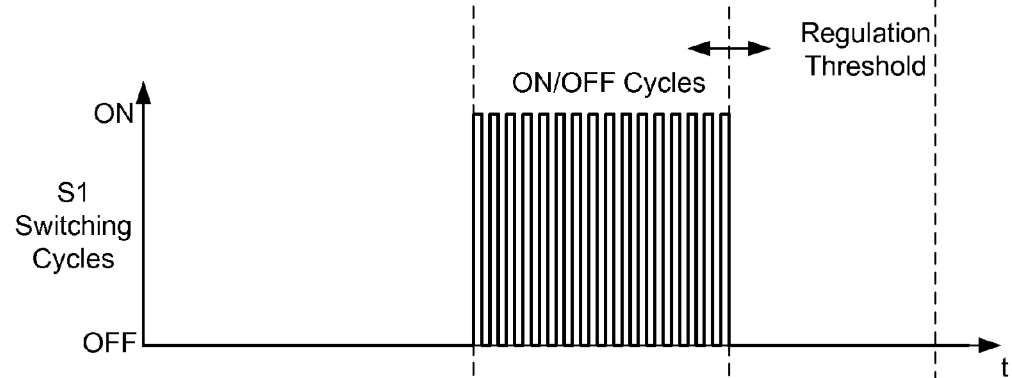


FIG. 3B

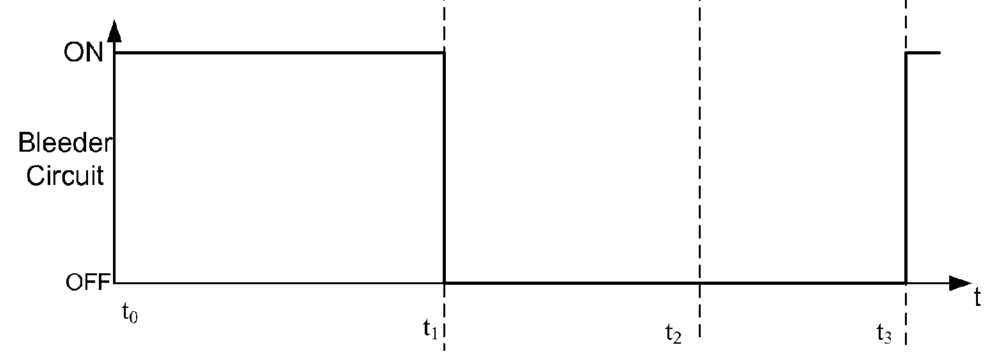


FIG. 3C

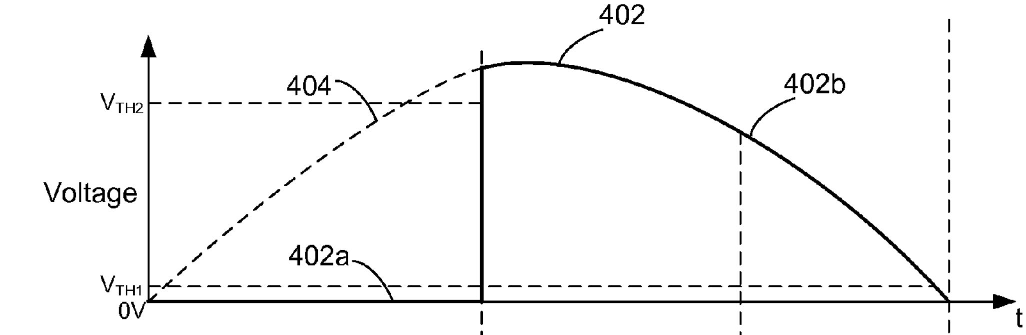


FIG. 4A

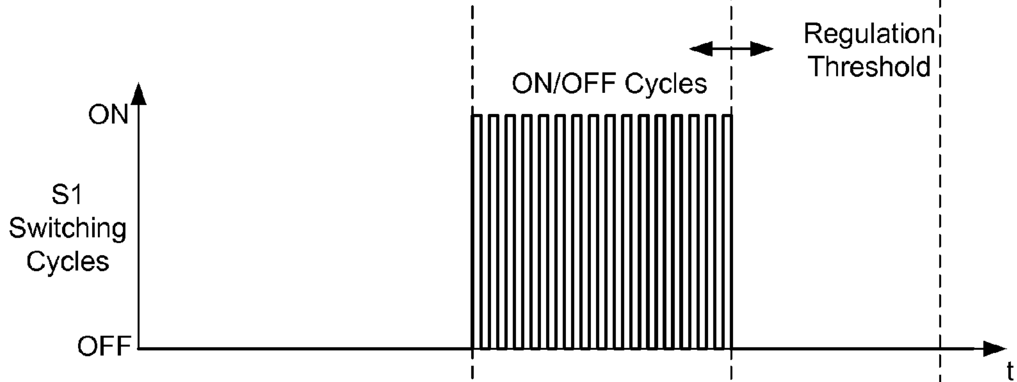


FIG. 4B

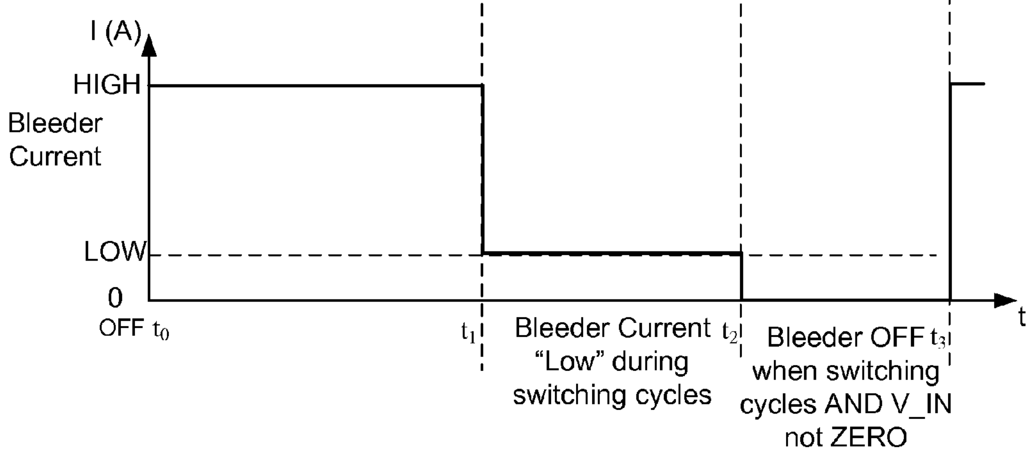


FIG. 4C

DYNAMIC BLEEDER CURRENT CONTROL FOR LED DIMMERS

CROSS-REFERENCE TO RELATED APPLICATION(S)

This application claims priority under 35 U.S.C. §119(e) to U.S. Provisional Patent Application Ser. No. 62/050,704, "Dynamic Bleeder Current Control For LED Dimmer," filed Sep. 15, 2014, which is incorporated herein by reference in its entirety.

BACKGROUND

1. Technical Field

The present disclosure relates to driving LED (Light-Emitting Diode) lamps and, more specifically, to adaptively dimming the LED lamps.

2. Description of the Related Arts

A wide variety of electronics applications now use LED lamps. These applications include architectural lighting, automotive head and tail lights, backlights for liquid crystal display devices, flashlights, and electronic signs. LED lamps have significant advantages compared to conventional lighting sources, such as incandescent lamps and fluorescent lamps. These advantages include high efficiency, good directionality, color stability, high reliability, long life time, small size, and environmental safety. Accordingly, LED lamps have replaced conventional lighting sources in many applications. For example, LED lamps are often used in applications where the brightness of the light source is adjusted, such as in a dimmable lighting system.

Dimmable lighting systems often use phase cut dimmer switches that employ a triac device to regulate the power delivered to a lamp by conducting during a certain period of an AC voltage supplied to the triac. To maintain the triac in the conducting state, a minimum holding current needs to be supplied to the triac. However, because LED lamp loads vary widely, triac devices may be unable to operate reliably. Furthermore, the minimum holding current varies widely among triac devices, which may further complicate the design of LED-based dimmable lighting systems. When the current through the triac device is less than a minimum holding current threshold, the triac device resets and pre-maturely turns off. As a result, LED lamps may prematurely turn off when they should be on, which may result in a perceivable light flicker or complete failure in the LED lamp.

SUMMARY

LED lamp systems as described herein include a dimmer switch and a bleeder circuit. The bleeder circuit provides a bleeder current to prevent the dimmer switch from turning off prematurely. Triac dimmers usually require about 100-200 mA to be turned on during a triggering operating mode. When triggered, triac dimmers enter into a triac conducting operating mode, where a triac dimmer continues to conduct until the current through the triac dimmer drops below a threshold current level (e.g., 5-20 mA). During the conducting operating mode, a triac dimmer may turn off when the current through the triac dimmer drops below the threshold current level, resulting in a perceivable flicker in the LED lamp. The bleeder circuit may monitor the AC input voltage outputted by the dimmer switch. When the AC input voltage is less than a first threshold, the bleeder circuit provides a bleeder current. When the AC input voltage is greater than a second threshold, the bleeder circuit adjusts the bleeder current to less than a predetermined level.

The features and advantages described in the specification are not all inclusive and, in particular, many additional features and advantages will be apparent to one of ordinary skill in the art in view of the drawings and specification. Moreover, it should be noted that the language used in the specification has been principally selected for readability and instructional purposes, and may not have been selected to delineate or circumscribe the inventive subject matter.

BRIEF DESCRIPTION OF THE DRAWINGS

The teachings of the present disclosure can be readily understood by considering the following detailed description in conjunction with the accompanying drawings.

FIG. **1** is a circuit diagram illustrating an LED lamp system, according to one embodiment.

FIG. **2** is a circuit diagram illustrating an LED lamp system, according to one embodiment.

FIG. **3**A illustrates example voltage waveforms of the LED lamp system of FIG. **2**, according to one embodiment.

FIG. **3**B illustrates an example control signal waveform of the LED lamp system of FIG. **2**, according to one embodiment.

FIG. **3**C illustrates an example bleeder circuit control signal waveform of the LED lamp system of FIG. **2**, according to one embodiment.

FIG. **4**A illustrates example voltage waveforms of the LED lamp system of FIG. **2**, according to another embodiment.

FIG. **4**B illustrates an example control signal waveform of the LED lamp system of FIG. **2**, according to another embodiment.

FIG. **4**C illustrates example bleeder current waveforms of the LED lamp system of FIG. **2**, according to another embodiment.

DETAILED DESCRIPTION OF EMBODIMENTS

The Figures (FIG.) and the following description relate to embodiments of the present disclosure by way of illustration only. It should be noted that from the following discussion, alternative embodiments of the structures and methods disclosed herein will be readily recognized as viable alternatives that may be employed without departing from the principles of the present disclosure.

Reference will now be made in detail to several embodiments of the present disclosure, examples of which are illustrated in the accompanying figures. It is noted that wherever practicable similar or like reference numbers may be used in the figures and may indicate similar or like functionality. The figures depict embodiments of the present disclosure for purposes of illustration only. One skilled in the art will readily recognize from the following description that alternative embodiments of the structures and methods illustrated herein may be employed without departing from the principles of the embodiments of the disclosure described herein.

FIG. **1** is a circuit diagram illustrating an LED lamp system **100** comprising an alternating current (AC) mains **114**, a dimmer switch **104**, and an LED lamp circuit **102**. The AC mains **114** provides an AC voltage **122** to the LED lamp circuit **102**. The dimmer switch **104** is coupled in series with the AC mains **114** and the LED lamp circuit **102** including an LED string **112**. The LED string **112** includes one or more LEDs. The dimmer switch **104** controls the amount (i.e., intensity) of light output by the LED string **112** by phase modulating the AC mains **114** to provide a regulated AC input voltage to the LED lamp circuit **102**. In one embodiment, the dimmer switch **104** is a phase cut dimmer including a triac device (not shown). A triac device included in the dimmer switch **104** is a bidirectional device that can conduct current in either direction when it is turned on (or triggered). One example of a dimmer switch that includes a triac device is described in U.S. Pat. No. 7,936,132. When the dimmer switch **104** including a triac device is turned on, the dimmer switch **104** continues to conduct until the current through the dimmer switch **104** and the LED string **112** drops below a holding current threshold.

The dimmer switch **104** determines the amount of adjustment applied to AC voltage **122** provided by the AC mains **114** based on the value of a dimming input signal **116** applied to the dimmer switch **104**. That is, the AC input voltage outputted by the dimmer switch is generated based on the value of the dimming input signal **116**. In some implementations, the dimming input signal **116** is an analog signal produced by a knob, slider switch, or other suitable electrical or mechanical device capable of providing an adjustment signal with a variable range of adjustment settings. In other implementations, the dimming input signal **116** is a digital signal. The dimmer switch **104** outputs an AC input voltage **118** to the LED lamp circuit **102**. The LED lamp circuit **102** adjusts the light output intensity of the LED string **112** substantially proportionally to the received AC input voltage **118**, exhibiting behavior similar to incandescent lamps. The LED lamp circuit **102** controls the current through the LED string **112** in a regulated manner that provides a smooth transition in light intensity level output of the LED lamp circuit **102** responsive to the dimming input signal **116** without perceivable flicker.

The LED lamp circuit **102** comprises a rectifier circuit **106**, a bleeder circuit **108**, a driver circuit **110**, and the LED string **112**. The rectifier circuit **106** receives the AC input voltage **118** and outputs a rectified voltage **120** corresponding to the AC input voltage **118**. The dimming level of the LED string **112** may be adjusted such that the current through the LED string **112** is below the holding current threshold of the triac device of the dimmer switch **104**. In such case, the bleeder circuit **108** ensures the triac device of the dimmer switch **104** to remain conducting while the LED string **112** can be adjusted within a dimming setting. The bleeder circuit **108** turns on to provide a bleeder current when the AC input voltage **118** is below a first threshold voltage. As such, the bleeder circuit **108** provides a current path across the output of the rectifier circuit **106**. The bleeder current provided by the bleeder circuit **108** discharges an input capacitor and provides a low impedance current path to ensure the triac device of the dimmer switch **104** to function properly. The internal timer of the triac device of the dimmer switch **104** can reset properly and charge up at the same time, which prevents dimmer phase jitter from cycle to cycle. In some embodiments, the bleeder circuit **108** provides bleeder current at different levels to reduce thermal loss and to increase the over-all system efficiency. When the AC input voltage **118** exceeds a second threshold voltage, the bleeder circuit **108** reduces the bleeder current. The second threshold voltage is greater than the first threshold voltage. Details of the bleeder circuit **108** will be further described with reference to FIG. **2**. The driver circuit **110** provides a driving current to the LED string **112**. The driver circuit **110** switches on and off thereby to regulate the driving current through the LED string **112** according to a duty cycle determined based on the rectified voltage **120**.

FIG. **2** is a circuit diagram illustrating an LED lamp system **100** including a dimmer switch **104** used in conjunction with an LED lamp circuit **102**. The LED lamp circuit **102** controls dimming of the LED string **112** to achieve the desired dimming based on the dimming input signal **116**. The LED lamp circuit **102** adaptively controls dimming in a manner that reduces or eliminates perceivable flickering of the LED string **112** throughout the dimming range, and causes the LED string **112** brightness to respond quickly and smoothly when the dimmer switch **104** is adjusted. In the illustrated example, the rectifier circuit **106** comprises a diode bridge **202** and a capacitor **204**. The rectifier circuit **106** provides a rectified voltage **120**, which is an unregulated direct current (DC) voltage to the bleeder circuit **108**. The capacitor **204** is coupled in parallel to the output of the diode bridge **202**. The diode bridge **202** generates a rectified voltage **120** based on the AC input voltage **118** outputted by the dimmer switch **104** based on the dimming input signal **116**. The rectified voltage **120** is provided to the capacitor **204**.

The bleeder circuit **108** comprises a bleeder circuit controller **206**, a bleeder current switch **208**, and a resistor **210**. The bleeder circuit controller **206** regulates the bleeder current switch **208** to provide a bleeder current path across the output of the rectifier circuit **106** when the AC input voltage **118** outputted by the dimmer switch **104** is below a first threshold voltage. The bleeder circuit controller **206** monitors the AC input voltage **118**, detects characteristics of the AC input voltage **118**, and determines when the AC input voltage **118** reaches the first threshold voltage indicating that the AC input voltage **118** is at or near 0 volts (i.e., a zero crossing voltage). The bleeder circuit controller **206** may use one or a combination of digital or analog circuit techniques. In one implementation, the bleeder circuit controller **206** includes a digital sampling circuit (not shown) and a comparator (not shown). The digital sampling circuit samples the AC input voltage **118** at a specified interval or over a specified period of time. The samples are provided to the comparator that compares the value of a specified number of samples to detect whether the AC input voltage **118** is at or near the zero crossing voltage.

When the bleeder circuit controller **206** determines that the AC input voltage **118** is at or near the zero crossing voltage, i.e., below the first threshold voltage, the bleeder circuit controller **206** generates a control signal **242** to enable the bleeder circuit **108** by turning on the bleeder current switch **208** thereby to provide a path for the bleeder current through the resistor **210** across the output of the rectifier circuit **106**. The bleeder current switch **208** may be a semiconductor power switch such as a metal oxide field effect transistor (MOSFET) as illustrated, a bipolar junction transistor (BJT), and the alike. As illustrated, the source of the bleeder current switch **208** may be coupled to a terminal of the output of the rectifier circuit **106**, a drain may be coupled to the other terminal of the output of the rectifier circuit **106** via the resistor **210**, and a gate is coupled to the output of the bleeder circuit controller **206**. By determining when the AC input voltage **118** zero crossing occurs, the bleeder circuit controller **206** avoids enabling the bleeder circuit **108** during high dissipative periods and enables the bleeder circuit **108** when the triac of the dimmer switch **104** is in the OFF state. That is, when the AC mains **114** is disconnected from the dimmer switch **104**.

The bleeder circuit **108** provides a current path across the output of the rectifier **106** during specified time periods to provide a low impedance current path to ensure the triac device of the dimmer switch **104** operates properly, such as stabilizing the dimmer phase. For example, the bleeder circuit **108** detects when the rectified voltage **120** outputted by the rectifier circuit **106** is at or below a first threshold value during each half cycle of the AC input voltage **118**, at which point it enables the bleeder circuit **108** to provide a bleeder current having a value sufficient to discharge the capacitor **210**. The bleeder circuit **108** may provide a bleeder current at different levels to ensure the triac device of the dimmer switch **104** operates properly and to reduce the thermal loss. For example, a bleeder circuit **108** may provide a high bleeder current at around 250 mA to 300 mA and a low bleeder current at around a half or a quarter of the high current level. While the dimmer switch **104** operates in the conducting state, the bleeder circuit **108** may regulate the amount of the bleeder current supplied to the dimmer switch **104** to ensure the dimmer switch remains in the conducting state. Such a regulation scheme avoids enabling the bleeder circuit **108** when the amount of energy stored in the capacitor **204** in the rectifier circuit **106** is at the maximum during each half cycle of the AC input voltage **118**. This increases the overall system efficiency while ensuring the proper operation of the dimmer switch **104** because the bleeder circuit **108** is disabled during high dissipative operating periods, such as when the power stage is operating in output regulation mode.

The bleeder circuit **108** accurately detects the correct timing of the AC input voltage **118** to determine the bleeder current control and avoids enabling the bleeder circuit **108** when the amount of energy stored in the bulk capacitor **204** is at the maximum during each half cycle of the AC input voltage **118**. This increases the overall efficiency of the LED lamp system **100** while ensuring the proper operation of the dimmer switch **104**.

The bleeder circuit controller **206** reduces the bleeder current when the AC input voltage **118** is above a second threshold value during each half cycle of the AC input voltage **118**. In one implementation, the bleeder circuit controller **206** disables the bleeder circuit **108** when the AC input voltage **118** is above a second threshold value. That is, when the driver circuit **110** operates, the bleeder circuit **108** is disabled and the bleeder current is reduced to zero. The bleeder circuit controller **206** may receive from the power stage controller **216**, a signal **240** indicating whether the switching cycles of the driver circuit **110** have been enabled. The bleeder circuit controller **206** disables the bleeder circuit **108** by switching off the bleeder current switch **208** when the driver circuit **110** has been enabled.

In one embodiment, the bleeder circuit **108** provides different levels of bleeder current. For example, during periods when the driver circuit **110** is disabled, the bleeder circuit **108** may provide different levels of bleeder current to properly manage voltage and to reduce thermal loss. As another example, during periods when the driver circuit **110** is enabled, the current through the LED string **112** may still be below the holding current of the dimmer switch **104**. The bleeder circuit **108** may provide a bleeder current to ensure the dimmer switch **104** remains conducting while the driver circuit **110** is enabled. In one implementation, the power stage controller **216** determines whether the regulation threshold is met by determining whether the energy being delivered to the output stage **214** is sufficient to maintain the proper output regulation of the LED string **112**. The power stage controller **216** may measure the current loading of the dimmer switch **104** and compare the measured current to the holding current threshold or a range of threshold values. The regulation threshold value may be specified or dynamically adjusted based on the loading characteristics of the dimmer switch **104** and the LED string **112**. When the bleeder circuit **108** determines that the driver circuit **110** is not operating, and based on an indication to maintain the output regulation, for example, provided by the power stage controller **216**, the bleeder circuit **108** returns to the operating mode as previously described. The power stage controller **216** may generate the indication to maintain the output regulation in response to determining the regulation threshold is not met.

The driver circuit **110** provides a driving current to the LED string **112**. The driver circuit **110** comprises a power stage **212** and an output stage **214**. The power stage **212** regulates the amount of energy provided to the output stage **214**, and the output stage **214** supplies the driving current to the LED string **112**. The power stage **212** includes a power stage controller **216**, a power stage switch **218**, and an inductor **220**. The power stage controller **216** may detect the AC input voltage **118** outputted by the dimmer switch **104** and output a control signal **242** to activate or deactivate the power stage switch **218**. For example, in one implementation, the power stage controller **216** may comprise an input coupled to the output of the dimmer switch **104** and measure the AC input voltage **118** outputted by the dimmer switch **104**. When the measured AC input voltage **118** meets a specified threshold voltage level or range, the triac included in the dimmer switch **104** transitions into a conducting state during each half cycle of the AC input voltage **118**. The power stage controller **216** regulates the driving current provided to the LED string **112** by controlling the duty cycle of the power stage switch **218**. The power stage controller **216** generates a control signal **242** in a first state (e.g., ON) to activate the power stage switch **218** based on a determination that the measured AC input meets or exceeds the specified threshold value or range. When the AC input voltage **118** is at the threshold value during each half cycle of the AC voltage **122** of the AC mains **114**, the power stage controller **216** generates a control signal **242** that transitions from the first state (e.g., ON) to a second state (e.g., OFF) to maintain output regulation. On the other hand, when the power stage controller **216** determines that the measured AC input voltage **118** is greater than a threshold indicating that the amount of energy being delivered to the output stage **214** is sufficient to maintain proper output regulation, the power stage controller **216** generates a control signal **242** in the second state (e.g., OFF) to deactivate the power stage switch **218**. The power stage switch **218** may be a semiconductor power switch such as a MOSFET as illustrated, a BJT, and the alike.

The output stage **214** comprises a rectifier diode **222** and an output capacitor **224**. The anode of the rectifier diode **222** is coupled to the drain of the power stage switch **218** and the cathode of the rectifier diode **222** is coupled to the positive terminal of the output capacitor **224**. The rectifier diode **222** ensures the current through the LED string **112** flows from the anode of the LED string **112** to the cathode of the LED string **112**. The capacitor **224** is connected in parallel with the LED string **112**, where the anode of the LED string **112** is connected to the positive terminal of the output capacitor **224** and the cathode of the LED string **112** is connected to the negative terminal of the output capacitor **224**. The capacitor **224** maintains the voltage across the LED string **112** is substantially constant. The rectifier diode **222** and the capacitor **224** together ensure reliable operation of the LED string **112**.

FIGS. **3**A through **3**C illustrate example waveforms of the LED lamp system **100** of FIG. **2**. FIG. **3**A shows voltage waveforms of the LED lamp system **100** of FIG. **2**. Waveform **302** is the AC input voltage **118** outputted by the dimmer switch **104** and waveform **304** is the AC voltage **122** supplied by the AC mains **114**. Waveform **304** (dotted line) is superimposed on the waveform **302**. As illustrated, the AC input voltage **118** includes a first portion **302***a* where the AC input voltage **118** is zero and a second portion **302***b* where the AC input voltage **118** is non-zero. The first portion and the second portion alternate. FIG. **3**B illustrates an example waveform representing a control signal **242** generated by the power stage controller **216** of the LED lamp system **100** of FIG. **2**. As shown in FIG. **3**B, the power stage controller **216** generates a control signal **242** when the AC input voltage **118** meets or exceeds the specified threshold value V_{TH1} or range at time t_1. The control signal **242** cycles between ON and OFF states to switch on and off the power stage switch **218**. The power stage controller **216** continues to generate a control signal **242** that cycles between ON and OFF states until a regulation threshold (i.e., whether the energy being delivered to the output stage **214** is sufficient to maintain the proper output regulation of the LED string **112**) is met as previously described with respect to FIG. **2**.

FIG. **3**C illustrates an example waveform representing a control signal **242** generated by the bleeder circuit controller **206** of the LED lamp system **100** of FIG. **2**. As shown in FIG. **3**C, the bleeder circuit controller **206** monitors the waveform **302** of the AC input voltage **118** and enables the bleeder circuit **108** when the AC input voltage **118** is less than the threshold value V_{TH1}. As illustrated, during the period (t_0-t_1) corresponding to the first portion **302**_a_ of the AC input voltage **118**, the voltage level of the AC input voltage **118** is less than the first threshold value V_{TH1} and the bleeder circuit **108** is enabled to provide a bleeder current. The bleeder circuit controller **206** disables the bleeder circuit **108**, at time t_1, when the voltage level of the AC input voltage **118** is greater than the threshold value V_{TH2}. As illustrated, during the period (t_1-t_3) corresponding to the second portion **302**_b_ of the AC input voltage **118** when the voltage level of the AC input voltage **118** is non-zero, the bleeder circuit **108** is disabled. The bleeder circuit **108** is not enabled during high dissipative periods. As illustrated, the bleeder circuit **108** is disabled even during the period (t_2-t_3) when the switching of the power stage switch **218** is disabled, and enabled at or near the zero crossing voltage of the AC input voltage **118** when the dimmer switch **104** is turned off and the AC mains **114** is disconnected from the rectifier circuit **106**.

FIGS. **4**A-**4**C illustrate example waveforms of the LED lamp system **100** of FIG. **2** according to another embodiment. FIGS. **4**A and **4**B are equivalent to FIGS. **3**A and **3**B, respectively. As illustrated, the AC input voltage **118** includes a first portion **402**_a_ where the AC input voltage **118** is zero and a second portion **402**_b_ where the AC input voltage **118** is non-zero. The first portion and the second portion alternate. FIG. **4**C illustrates an example bleeder current waveform provided by the bleeder circuit **108** of the LED lamp system **100** of FIG. **2**. As shown in FIG. **4**C, the bleeder circuit generates a bleeder current having different output levels. During the period (t_0-t_1) corresponding to the first portion **402**_a_ of the AC input voltage **118**, the voltage level of the AC input voltage **118** is less than the first threshold value V_{TH1} and the bleeder circuit is enabled to provide a bleeder current to discharge the capacitor included in the rectifier circuit. The driver circuit **110** is enabled, at time t_1, when the voltage level of the AC input voltage **118** is greater than the threshold value V_{TH2}. During the period (t_1-t_3) corresponding to the second portion **402**_b_ of the AC input voltage **118** when the voltage level of the AC input voltage **118** is non-zero, the bleeder current is reduced. For example, as illustrated, during the time period (t_1-t_2), the bleeder current circuit **110** generates a bleeder current at a low level to ensure the triac included in the dimmer switch **104** remains in the conducting state while the power stage **212** switching cycles are enabled. The low level of the bleeder current is set based on the holding current threshold of the dimmer switch **104** and the driving current through the LED string **112**. During the time period (t_2-t_3), the bleeder current is reduced to approximately 0 A and the driver circuit **110** disables the switching cycles.

Upon reading this disclosure, those of skill in the art will appreciate still additional alternative designs for controlling dimming of an LED lamp using an adaptive bleeder current control. Thus, while particular embodiments and applications of the present disclosure have been illustrated and described, it is to be understood that the disclosure is not limited to the precise construction and components disclosed herein and that various modifications, changes and variations which will be apparent to those skilled in the art may be made in the arrangement, operation and details of the method and apparatus of the present disclosure disclosed herein without departing from the spirit and scope of the disclosure.

What is claimed is:

1. A light-emitting diode (LED) lamp, comprising:

an LED string including one or more LEDs;

a rectifier circuit configured to receive an AC input voltage and to generate a rectified voltage corresponding to the AC input voltage, the rectified voltage is a phase-cut AC input voltage indicating a dimming level;

a bleeder circuit coupled to the rectifier circuit and configured to turn on to provide a bleeder current at a first current level responsive to the AC input voltage less than a first threshold voltage and to reduce the bleeder current to a second current level responsive to the AC input voltage exceeding a second threshold voltage; and

an LED driver circuit configured to switch on or off a power stage switch according to a duty cycle based on the rectified voltage, to regulate a driving current through the LED string.

2. The LED lamp of claim **1**, wherein:

the AC input voltage includes a first portion during which the AC input voltage is zero and a second portion during which the AC input voltage is non-zero, the first portion alternating with the second portion; and

the first threshold voltage and the second threshold voltage are set such that the bleeder circuit is configured to turn on during the first portion of the AC input voltage and turn off during the second portion of the AC input voltage.

3. The LED lamp of claim **1**, wherein:

the AC input voltage includes a first portion during which the AC input voltage is zero and a second portion during which the AC input voltage is non-zero, the first portion alternating with the second portion;

the LED driver circuit is configured to switch on or off the power stage switch according to the duty cycle based on the rectified voltage during a part of the second portion of the AC input voltage;

the first threshold voltage is set such that the bleeder circuit is configured to turn on during the first portion of the AC voltage;

the second threshold voltage is set such that the bleeder circuit reduces the bleeder current to the second current level during said part of the second portion of the AC voltage; and

the bleeder circuit is configured to turn off during a remaining part of the second portion of the AC voltage.

4. The LED lamp of claim **1**, wherein the first threshold voltage is less than the second threshold voltage.

5. The LED lamp of claim **1**, wherein the bleeder current flows through a triac external to the LED string, the rectifier circuit, and the bleeder circuit.

6. The LED lamp of claim **1**, wherein the bleeder circuit comprises:

a first switch configured to be turned on to provide the bleeder current or turned off to stop the bleeder current; and

a first controller configured to generate a first control signal to turn on or off the first switch based on the AC input voltage.

7. The LED lamp of claim **6**, wherein the LED driver circuit comprises

a power stage switch configured to be turned on to connect the rectified voltage to the LED driver circuit and turned off to disconnect the rectified voltage to the LED driver circuit; and

a second controller configured to generate a second control signal having the duty cycle, the power stage switch being turned on or off responsive to the second control signal according to the duty cycle.

8. The LED lamp of claim **7**, wherein the first controller and the second controller are packaged in an integrated circuit.

9. The LED lamp of claim **1**, wherein the second current level is determined according to the duty cycle and a triac external to the LED string, the rectifier circuit, and the bleeder circuit.

10. A method of powering a light-emitting diode (LED) string, comprising:

receiving an AC input voltage and generating a rectified voltage corresponding to the AC input voltage, the rectified voltage being a phase-cut voltage indicating a dimming level;

determining a level of the AC input voltage;

providing a bleeder current at a first current level responsive to the AC input voltage being less than the first threshold voltage, and reducing the bleeder current to a second current level responsive to the AC input voltage exceeding the second threshold voltage; and

regulating a driving current through the LED string by switching on or off a power stage switch according to a duty cycle based on the rectified voltage.

11. The method of claim **10**, wherein:

the AC input voltage includes a first portion during which the AC input voltage is zero and a second portion during which the AC input voltage is non-zero, the first portion alternating with the second portion; and

the first threshold and the second threshold are set such that the bleeder current is at the first current level during the first portion of the AC input voltage and the bleeder current is at the second current level during the second portion of the AC input voltage.

12. The method of claim **10**, wherein:

the AC input voltage includes a first portion during which the AC input voltage is zero and a second portion during which the AC input voltage is non-zero, the first portion alternating with the second portion;

the power stage switch is switched on or off according to the duty cycle based on the rectified voltage during a part of the second portion of the AC input voltage;

the first threshold is set such that the bleeder current is at the first level during the first portion of the AC voltage;

the second threshold is set such that the bleeder current is at the second level during said part of the second portion of the AC voltage; and

the bleeder current is zero during a remaining part of the second portion of the AC voltage.

13. The method of claim **10**, wherein the first threshold voltage is less than the second threshold voltage.

14. The method of claim **10**, wherein the bleeder current is provided to flow through a triac external to the LED string.

15. The method of claim **10**, wherein the step of providing the bleeder current comprises generating a first control signal based on the AC input voltage to switch on or off a first switch to provide the bleeder current at the first level.

16. The method of claim **15**, wherein the step of regulating the driving current comprises generate a second control signal having the duty cycle, the power stage switch being turned on or off responsive to the second control signal according to the duty cycle of the second control signal.

17. The method of claim **10**, wherein the duty cycle is determined according to a dimming control signal indicative of the dimming level.

18. The method of claim **10**, wherein the second current level is determined according to the duty cycle and a triac external to the LED string, the rectifier circuit, and the bleeder circuit.

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